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Elaine D. Flynn

Western Kentucky University, elaine.flynn@wustl.edu

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CARBON AND OXYGEN ISOTOPE STUDY OF CARBONATES FROM
WATLING'S BLUE HOLE AND BLUE HOLE FIVE, SAN SALVADOR, BAHAMAS

A Capstone Experience/Thesis Project

Presented in Partial Fulfillment of the Requirements for

The Degree Bachelor of Science with

Honors College Graduate Distinction at Western Kentucky University

By

Elaine D. Flynn

Western Kentucky University

2013

CE/T Committee:

Dr. Cathleen Webb, Advisor

Dr. Lisa Park Boush

Dr. Leslie Baylis

Approved by

Advisor

Department of Chemistry

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ABSTRACT

Carbonate platforms, such as the Bahamas, formed through deposition and sea level fluctuations. These platforms contain records of rapid interglacial climate change and are useful in studying the impacts of climate change on similar tropical carbonate environments. Blue holes are dissolution lakes that may be beneficial for understanding climate change and anthropogenic impact. A $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ study was conducted on lake sediment core samples from Watling's Blue Hole and Blue Hole Five on San Salvador Island, Bahamas. These lakes are located in a failed housing development and Watling's Blue Hole was once part of an early 19th century plantation which modified the landscape of the surrounding watershed. These lakes are hydrologically connected to the ocean and are tidally influenced: seawater enters through karstic bedrock, while surface water is fresher because of rainwater inputs. Watling's Blue Hole Site 2 has the older basal date of ~6,870 cal. yr. BP while Blue Hole Five Site 3 basal date was ~5,340 cal. yr. BP. These cores differed compositionally and may be a result of the anthropogenic impact, at least in the very top of the cores. The similarities and differences between Watling's Blue Hole and Blue Hole Five aid in understanding the impact of anthropogenic and climate change on carbonate platforms as these characteristics vary throughout the Holocene.

Keywords: Blue Hole, Bahamas, Stable Isotopes, Climate Change, Geology, Chemistry

Dedicated to the REU Bahamas 2012 Team

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VITA

November 8, 1991.....Born –Demossville, Kentucky

2010.....Carol Martin Gatton Academy of Mathematics and
Science, Bowling Green, Kentucky

2011.....Semester at Sea Short Term Voyage

2012.....National Science Foundation Research Experience
for Undergraduates

2013.....Western Kentucky University, Bowling Green,
Kentucky

FIELD OF STUDY

Major Field 1: Geology

Major Field 2: Chemistry

Minor Field: Mathematics

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CHAPTER 1

INTRODUCTION

The Holocene epoch (11,500 cal. yr. BP to the present) has been viewed as climatically stable with “little evidence of the abrupt millennial-scale climatic shifts that characterize glacial periods” (deMenocal et al., 2000). However, studies have shown that there are larger and more frequent climate variations than were commonly recognized (Mayewski et al., 2004). According to Steig, “substantial and possibly global climate oscillations have occurred during the past 10,000 years, with pacing similar to the larger magnitude glacial events” (1999). Mayewski et al. used the term rapid climate change (RCC) to represent the short intervals (cooling events) of Holocene climate change (2004). The RCCs includes the periods known as the “Little Ice Age” and “Medieval Warm Period” and are considered rapid due to occurring within a few hundred years or shorter (Mayewski et al., 2004).

The first RCC occurred between 9,000-8,000 cal. yr. BP and was labeled by Mayewski et al. as the “Glacial Aftermath” (2004). This cooling event occurred while ice sheets were still present over the Northern Hemisphere (Mayewski et al., 2004) and had a near global impact (deMenocal et al., 2000). In the low latitudes, specifically in the Caribbean, the trade wind strength and/or rainfall fluctuated dramatically with a

persistent drought in Haiti, the Amazon basin, Pakistan, and Africa (Mayewski et al., 2004).

The RCCs occurring after the Glacial Aftermath RCC varied in intensity and geographic extent but involved low-latitude aridity and high latitude cooling similar to trends during the Pleistocene (Mayewski et al., 2004). Steig suggested that the mid-Holocene (7,000-5,000 cal. yr. BP) was a “period of particularly profound change. During this interval, temperatures appear to have declined across much of the globe” (1999). The decline in temperatures are usually seen in records from the polar regions (such as Antarctica, Greenland, and the eastern Canadian Arctic) while the lower latitudes either cooled, became more arid, or both (Steig, 1999).

According to Mayewski et al., these cool poles, dry-tropics RCCs occurred four times within the Holocene with the RCCs from 6,000-5,000 and from 3,500-2,500 cal. yr. BP covering the most extensive area (2004). Studies have shown various climatic changes throughout the lower latitudes for the 6,000-5,000 cal. yr. BP RCC. Mayewski et al. identifies that during the 6,000-5,000 cal. yr. BP RCC the Caribbean became wetter (2004). However, ostracod shells from Lake Miragoane in Haiti suggest high lake levels between 7,000 and 5,300 cal. yr. BP with an increase in evaporation compared to precipitation at 5,200 cal. yr. BP resulting in dryer conditions (Hodell et al., 1991). According to Metcalfe et al., a study completed by Xelhuantzu Lopez in 1994 suggested a shift in pollen records indicate more arid conditions from Lake Zacapu in Mexico (2000). Additional records throughout Mexico also suggest dry, warm periods around 6,000-5,000 cal. yr. BP but a stable isotope record from La Piscina de Yuriria, Mexico

suggest a generally moist environment from 6,700-5,500 cal. yr. BP (Metcalf et al., 2000).

The 3,500-2,500 cal. yr. BP RCC was a time of aridity in the Caribbean (Mayewski et al., 2004). However, a diatom record from Lake Patzcuaro, Mexico studied by Ruth Patrick suggested a wetter period from 3,300-2,300 years ago—note that radiocarbon dating was not completed during this study (Metcalf et al., 2000). Stable isotope records were also completed for Lake Patzcuaro by Bridgewater that suggest wet conditions between 3,530-2,390 cal. yr. BP, however, stable isotope records from La Piscina de Yuriria suggest a series of dry periods after 3,000 cal. yr. BP (Metcalf et al., 2000).

The RCCs from 4,200-3,800 and from 1,200-1,000 cal. yr. BP were less widespread and “evidence for the RCC events at 4,200-3,800 and 1,200-1,000 cal. yr. BP appear in fewer records” but Mayewski et al. did note that records from Haiti indicate that it was generally wet (2004). Hodell et al. noted that a “dry episode” occurred from ~2,400 to 1,500 cal. yr. BP followed by a “brief period of wetter conditions” between ~1,500 and 900 cal. yr. BP (1991). This differs from records from central Mexico and the Yucatan Peninsula which suggest a period of aridity around 1,000 cal. yr. BP (Metcalf et al., 2000).

The last RCC is suggested to have occurred from 600-150 cal. yr. BP, yet due to high resolution records for this time being relatively scarce and anthropogenic influences it is difficult to determine the time frame of the last RCC (Mayewski et al., 2004). A distinct drop in CO₂ and a rise in CH₄ during this interval suggest wet conditions in the

tropics and solar variability may have had a strong influence on climate during this time (Mayewski et al., 2004). This interval saw Florida and Haiti becoming more arid (Mayewski et al., 2004). Metcalfe et al. also suggest arid conditions during this RCC for areas in Mexico, though a few of their reviews indicate shifts to wetter conditions during this time period (2000). Records from Storrs Lake and Clear Pond on San Salvador Island have sandy facies at 700 YBP that correspond to the 600-150 RCC event from arid to moist conditions and have been recognized in other soil and lake cores from San Salvador Island (Park, 2012).

The anthropogenic impact of climate change and the influence climate change has had on culture can be recognized from the more recent RCCs. According to Mayewski et al., “The 1,200-1,000 cal. yr. BP RCC event coincided with the drought-related collapse of Mayan civilization and was accompanied by a loss of several million lives” (2004). However, while multidecadal droughts have been suggested to be the cause of the collapse of the Mayan civilization, it remains controversial due to “dating uncertainties and insufficient temporal resolution in paleoclimatic records” (Kennett et al., 2012). Kennett et al. examined climate records for the past 2,000 years in cave deposits from Yok Balum Cave in Belize and suggested records of high rainfall and droughts that correspond to the rise and fall of the Mayan civilization (2012). The dry periods may have led to famine, disease, death, and movement of people groups which could have contributed to the fall of the Mayan civilization (Kennett et al., 2012).

The collapse of other civilizations including the Greenland’s Norse colonies and the Akkadian Empire directly correlated to RCC events (Mayewski et al., 2004). The Lucayan Tainos, the first inhabitants of San Salvador Island, arrived just after the period

of Caribbean aridity suggesting that climate may influence migration patterns, activities, and survival as a culture (Park 2012). Park suggested that this relationship between climate and culture should be examined further to better understand the archaeological record and climate change record relationship (2012).

Though studies have been completed, there are still questions to be answered relating to the Holocene climate and anthropogenic climate change. Mayewski et al. noted, “Although the climate of the Holocene has sustained the growth and development of modern society, there is surprisingly little systematic knowledge about climate variability during this period” (2004). They suggest that if the anthropogenic climate change is to be understood it is important to fully understand the natural variability within the recent past (Mayewski et al., 2004). Steig suggested “because these [global climate] oscillations occurred under conditions similar to those of today they bear more directly on our understanding of contemporary climate change than do the events of the last glacial period” (1999). This emphasizes the need to study Holocene climate variation regionally to better understand the effects of RCCs, contemporary climate change, and the relationship between the two.

Carbonate platforms formed through deposition and sea level fluctuations. These platforms contain records of rapid interglacial climate change and are therefore useful in studying the impacts of climate change on similar environments. The Bahamas Archipelago are carbonate platforms composed of Quaternary carbonates and dominated by exposed Pleistocene carbonates (Mylroie, Carew, & Vacher, 1995; Carew & Mylroie, 1994). According to Carew and Mylroie, “the glacio-eustatic sea level changes of the Quaternary have alternately flooded and exposed the Bahamian platforms, subjecting

them to cycles of carbonate deposition and dissolution, respectively” (1994). Since carbonate deposition only occurs when platforms are flooded, currently deposition is not occurring on San Salvador Island except for areas of the platform under the lakes, blue holes, and ocean.

Blue holes are flooded karst features that formed from caves or failure of the steep margins of the Bahama banks (Carew & Mylroie, 1994). According to Vermette and Hudson, blue holes are “water-filled pit caves” formed “during periods of low sea level, as during Pleistocene glaciation, pit caves form by dissolution of limestone” (2001). Blue holes are categorized into two types: ocean holes open directly into a lagoon or the ocean, are tidally influenced and contain only marine water while inland blue holes open on land, may be tidally influenced, and have water qualities ranging from fresh to marine (Carew & Mylroie, 1994).

According to a study by Dix, Patterson, and Park “little is known about sedimentary dynamics of marine saline lakes and ponds [and blue holes] when compared to continental saline lakes. Yet, marine-lake basins are likely excellent sedimentary archives of high-frequency patterns of Holocene paleoclimate” (1999). This is due to their location at or very near to the sea level that allows the water chemistry to correspond quickly to even small changes in sea level or local climate (Dix et al., 1999). The study by Dix, Patterson, and Park was able to obtain sediment archives of late Holocene climate and sea-level variation over a 1,500 year interval for ponds on Lee Stocking Island, Bahamas (1999). A paleoclimate study on Church Blue Hole located on Andros Island, Bahamas also suggest the usefulness of marine saline lakes and ponds in understanding RCC events in the Caribbean (Kjellmark, 1996). The cores from this blue

hole suggest that a late Holocene dry period occurred that may correlate to the widespread dry period in the Caribbean between 3,200-1,500 cal. yr. BP (Kjellmark, 1996). Therefore, the inland blue holes of the Bahamas and other locations, like the ponds on Lee Stocking Island and Andros Island, represent the cumulative dissolution that occurred during many sea level fluctuations (Carew & Mylroie, 1994). Inland blue holes are useful in studying island hydrology and assessing the impact of climate change and anthropogenic impact (Vermette & Hudson, 2001).

This study examines carbon and oxygen stable isotopes analysis assist in an ongoing study to determine the characteristics of anthropogenic and climate change on carbonate platforms for the past 6,000 years. This study will compare the impacts of anthropogenic and climate change on two blue holes located in the same region of San Salvador Island, Bahamas.

Site Location

San Salvador Island is located on an isolated carbonate platform southeast of the Great Bahamas Bank approximately 600 km from Miami Florida (Figure 1.1). It is one of the 700 islands included in the Bahamas Archipelago and is the eastern-most island. Blue holes, dissolution lakes, and interdunal lakes exist on the island. The island also has other dissolution features such as banana holes, pit caves, and flank margin caves. Watling's Blue Hole and Blue Hole Five are located on the southwest side of San Salvador Island in a failed housing development. Watling's Blue Hole was once part of an early nineteenth century cotton plantation which modified the landscape of the surrounding watershed. Watling's Blue Hole (Figure 1.2) is circular in shape with an average depth of 8 meters

while Blue Hole Five (Figure 1.3) is keyhole shaped with an average depth of 6 meters.

These blue holes are tidally influenced and are brackish.

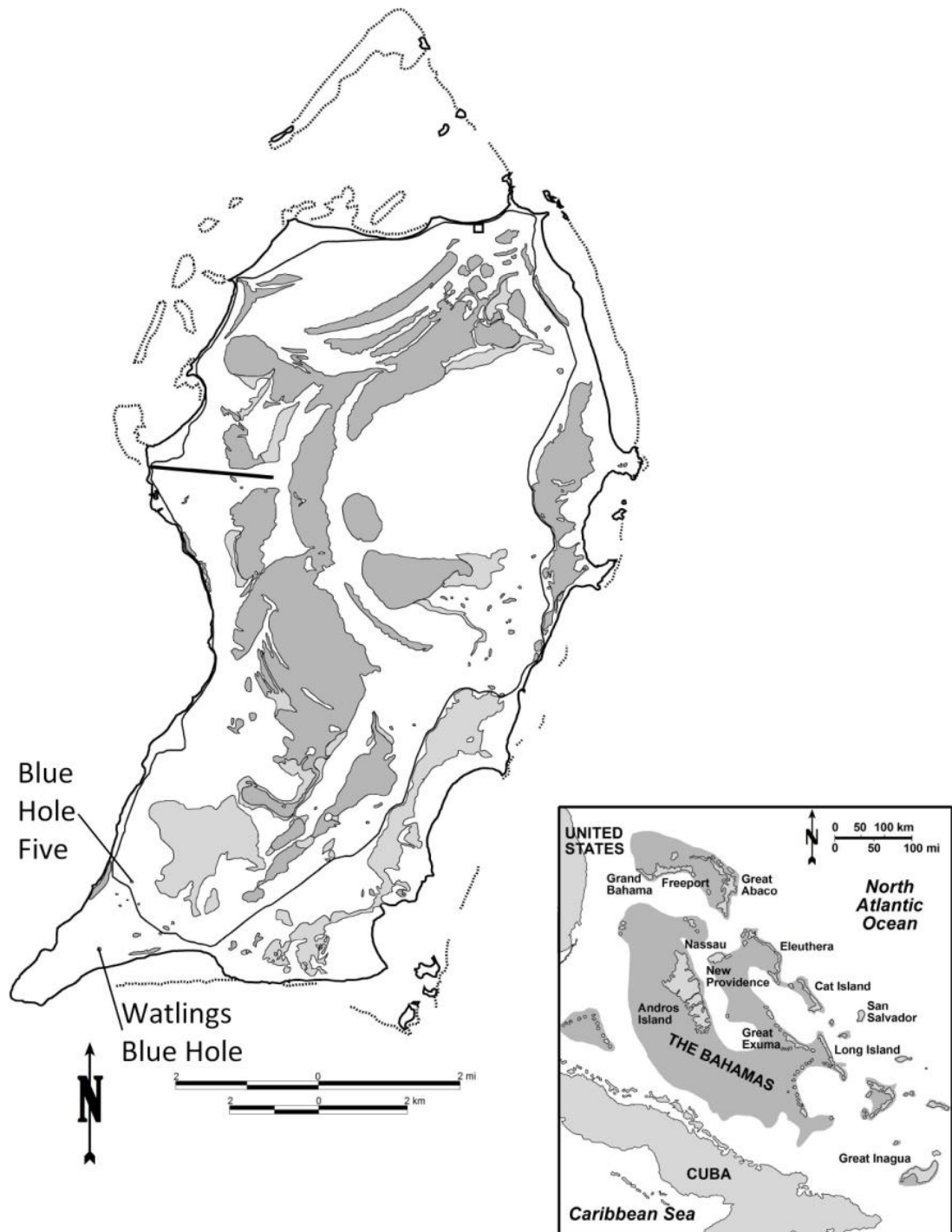


Figure 1.1: San Salvador Island, Bahamas. Watling's Blue Hole and Blue Hole Five located to the Southwest. (Park, 2012)



Figure 1.2: Watling's Blue Hole during low tide. Photo Courtesy of Patrick Quillen.



Figure 1.3: Blue Hole Five

CHAPTER 2

METHODS

During June of 2012, a Research Experience for Undergraduates project entitled “Field Research on Bahamian Lakes—Exploring Records of Anthropogenic and Climate Change” collected sediment cores from Watling’s Blue Hole and Blue Hole Five at three sites (Figure 2.1).



Figure 2.1: Coring Blue Hole Five. Photo Courtesy of Scott Pollan.

These cores were split and analyzed at the National Lacustrine Core Facility (LacCore) for initial core studies. Initial lithological core descriptions (LCD) were completed to define the lithology following the nomenclature defined in Schnurrenberger et al. (2003). Loss on ignition (LOI) was used to determine the percent of organic, carbonate, and inorganic (silicate) material in the sediment through the procedures outlined in Heiri et al. (2001). The cores were scanned for whole core x-ray fluorescence (XRF) analysis to determine the major and minor elements throughout the core. Scanning electron microscopy (SEM) was used to assist in further characterization of the sediments.

Radiocarbon dating was completed for the base of each core and multiple depths throughout the cores to create an age model for sediment deposition based on Bauuw and Christen (2011). One core from each blue hole was chosen to be sampled for stable carbon and oxygen isotope ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) data based on the age model and composition. Watling's Blue Hole Site 2 and Blue Hole Five Site 3 were subsampled at four centimeter intervals and were prepared randomly for isotope analysis using procedures outlined by LacCore.

Sediments were treated with commercial bleach and water solution for 22 hours to destroy organic matter that may interfere with the mass spectrometer. The bleach was rinsed from the samples using a centrifuge at 3,000 RPM for five minute intervals and decanting the supernatant. This process was repeated eight times until the smell of bleach (chlorine, or swimming pool smell) was no longer detected. Samples were screened to remove large particles using Nitex screen fabric screens and dried in an oven at 40°C for at least five days.

After samples were dried, sediment was ground in a mortar to homogenize and prepared for submission for analysis. Sample vials were labeled and sent to the University of Kentucky for isotopic analysis. Once isotopic analysis is completed, results will be integrated with previous data from the cores and radiocarbon dating. The climate models for Watling's Blue Hole and Blue Hole Five will be created and compared to better understand the impacts of anthropogenic activity.

CHAPTER 3

RESULTS

Watling's Blue Hole and Blue Hole Five differed compositionally. Cores from Watling's Blue Hole were fine to medium grained carbonate sands with few shells. Blue Hole Five cores were medium to coarse grained carbonate sands with shell beds. Blue Hole Five also has a green flocculent layer located at the top of each core. Watling's Blue Hole had more identifiable units than Blue Hole Five based on physical descriptions (LCD) and chemical analysis (LOI, XRF) as seen in the stratigraphic columns prepared for each lake (Figure 3.1 & 3.2).

Radiocarbon dating identified Watling's Blue Hole Site 2 to be the oldest core collected from both lakes. The basal date for this core is ~6,870 cal. yr. BP while Blue Hole Five Site 3 basal date was ~5,340 cal. yr. BP. Additional radiocarbon dates were collected from organic matter at intervals throughout the core to produce an age model of time versus deposition (Figure 3.3 & 3.4).

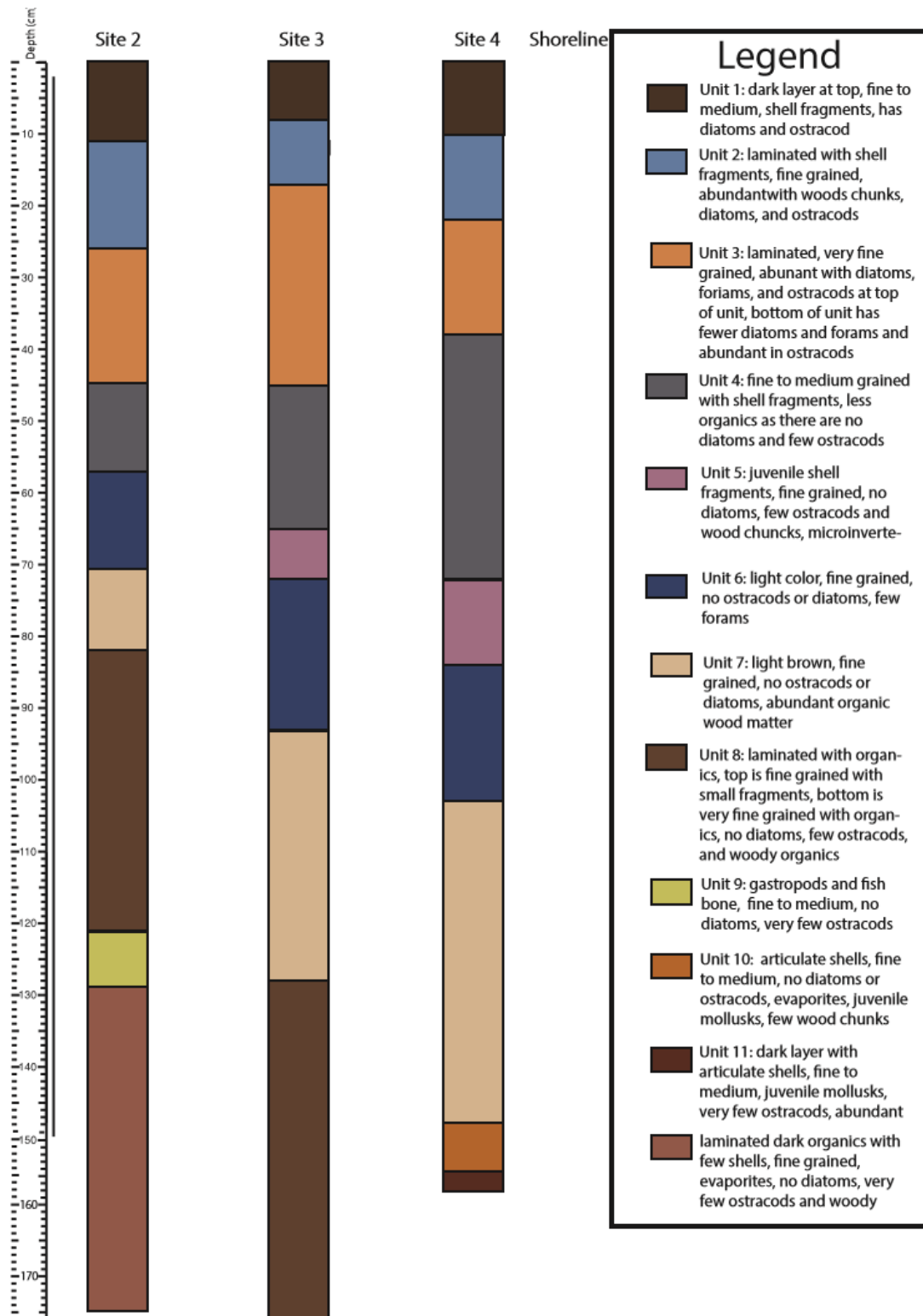


Figure 3.1: Watling's Blue Hole Stratigraphic Columns

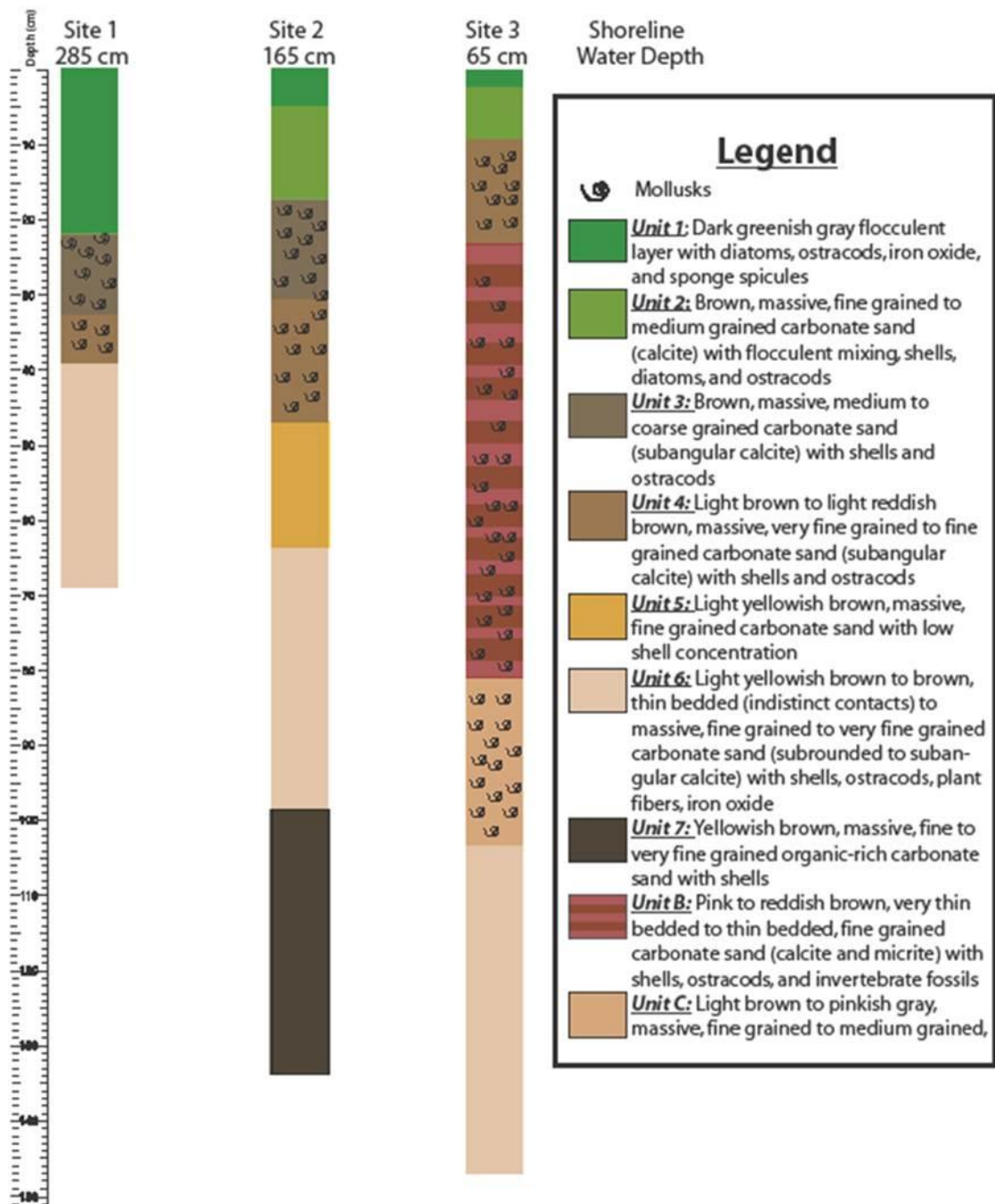


Figure 3.2: Blue Hole Five Stratigraphic Columns

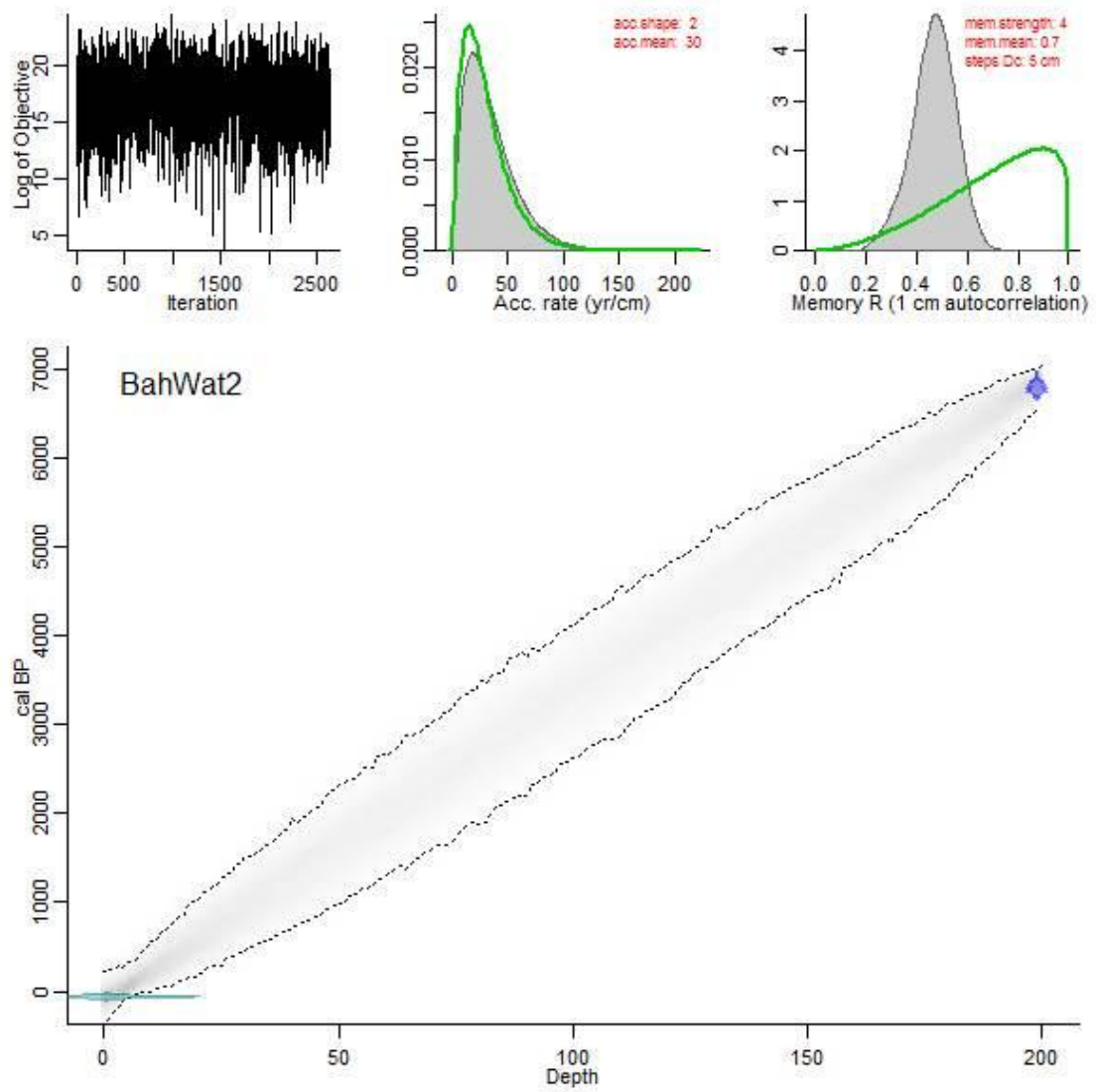


Figure 3.3: Watling's Blue Hole Site 2 Age Model

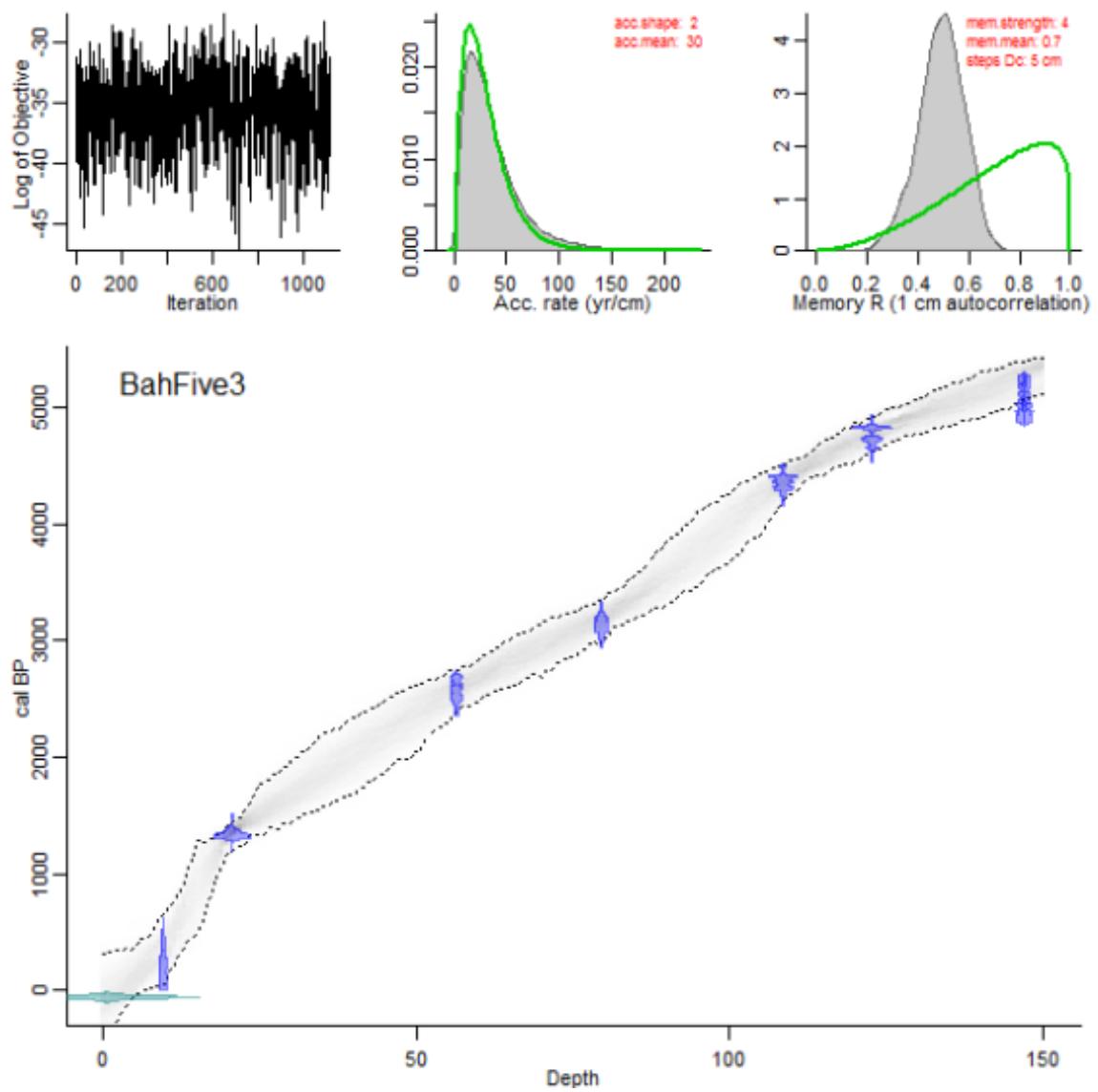


Figure 3.4: Blue Hole Five Site 3 Age Model

LOI data confirmed that the majority of the sediment for both lakes was carbonate, with varying amounts of terrestrial and aquatic organic material and very low, occasional inorganic pulses. The organic material in Watling's Blue Hole Site 2 was high (~30%) at the top of the core compared to the rest of the core which ranged from 5-20% (Figure 3.5). This site ranged from 0-10% inorganic material. The data suggest that these inorganic pulses seem to occur during specific intervals of time. Blue Hole Five Site 3 also has the highest percent (25-30%) of organic material at the top of the core (Figure 3.6). This can be visually identified by the two 1 cm beds of shells within the flocculent layer within the first 20 cm of the core. The rest of the core contains 5-20% organic material. The flocculent layer also seemed to have small pulses of inorganic material. The inorganic pulses reappear after a depth of 100 cm in the core which relates to ~2,600 cal. yr. BP and older based on the age model. The inorganic material for Blue Hole Five Site 3 does not seem to follow a time interval pattern like Watling's Blue Hole Site 2.

XRF data, collected at the Large Lakes Observatory (LLO), indicated elemental analysis differed between the lakes. Watling's Blue Hole Site 2 shows a strong visual correlation between iron and titanium (Figure 3.5). Blue Hole Five Site 3 does not show a visual correlation between iron and titanium throughout the core. At several locations, iron and titanium seem to correlate, for example near the top of the core, however, other locations do not correlate (Figure 3.6).

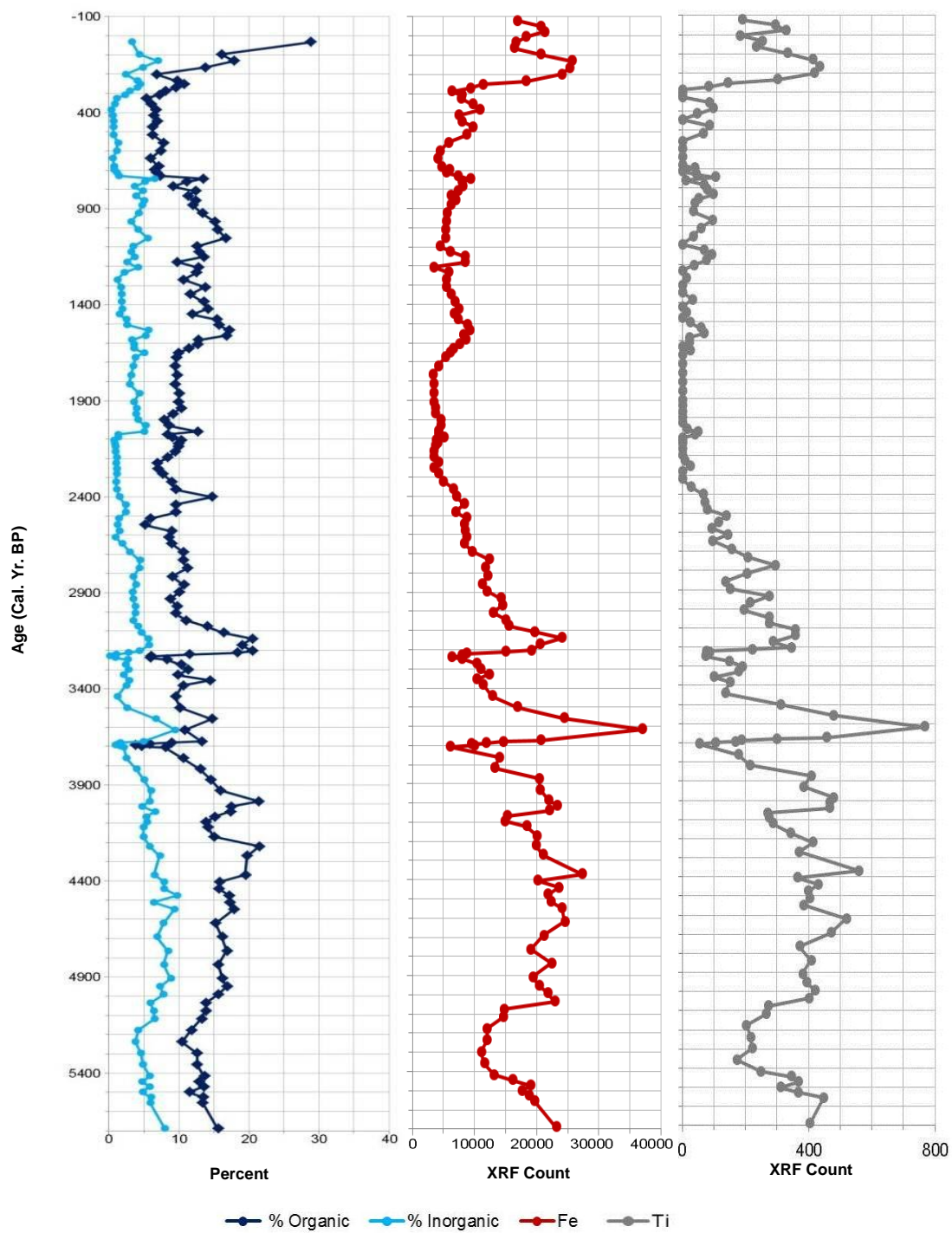


Figure 3.5: Watling's Blue Hole Site 2 LOI and XRF (iron and titanium) versus Age

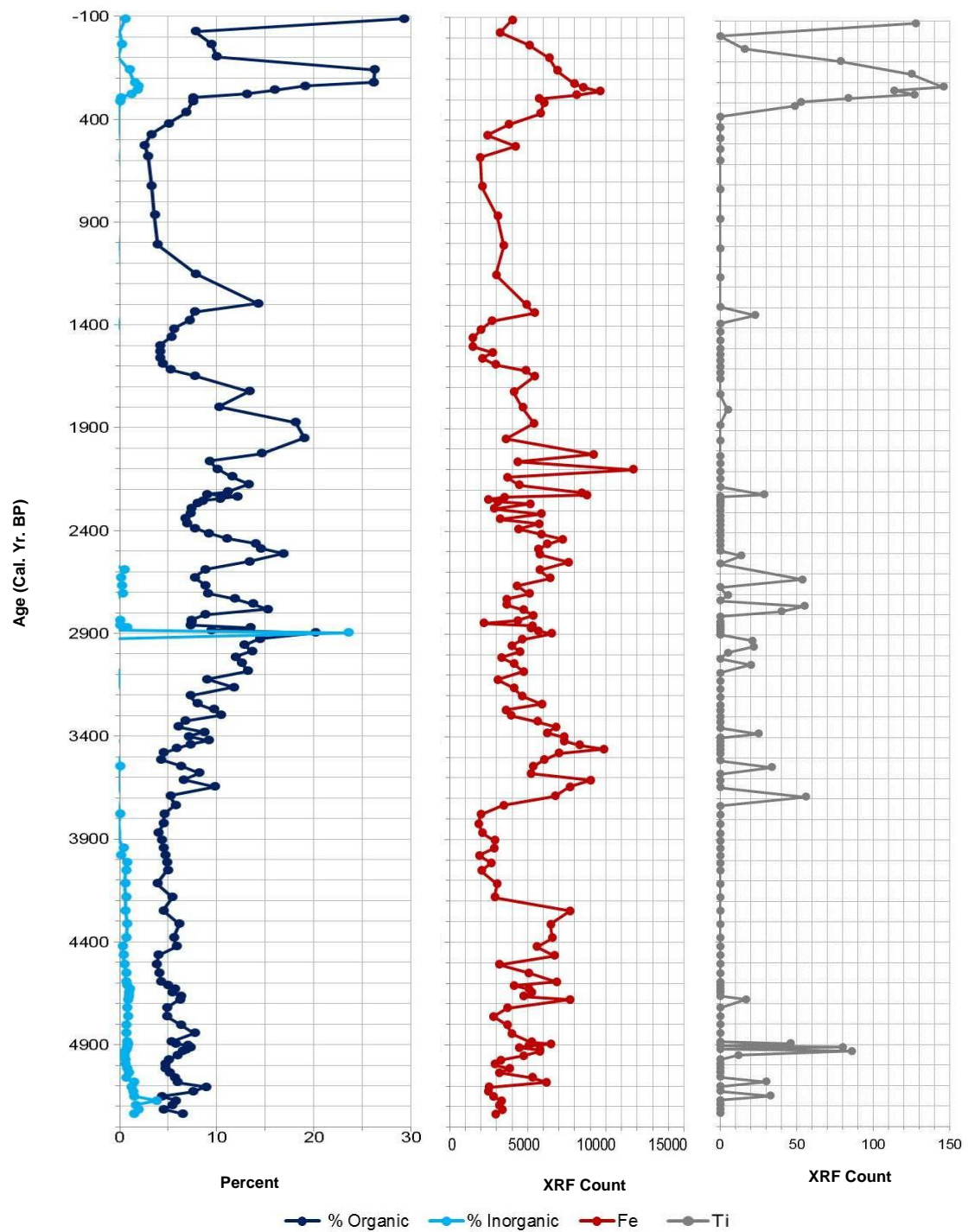


Figure 3.6: Blue Hole Five Site 3 LOI and XRF (iron and titanium) versus Age

Pyrite, an indicator of oxygen-poor, sulfuric, reducing conditions was identified in cores from both lakes through SEM (Figure 3.7). The SEM was also used to locate possible phytoliths and diatoms which may, in the future, assist in understanding the vegetation and environment throughout the past 6,000 years.

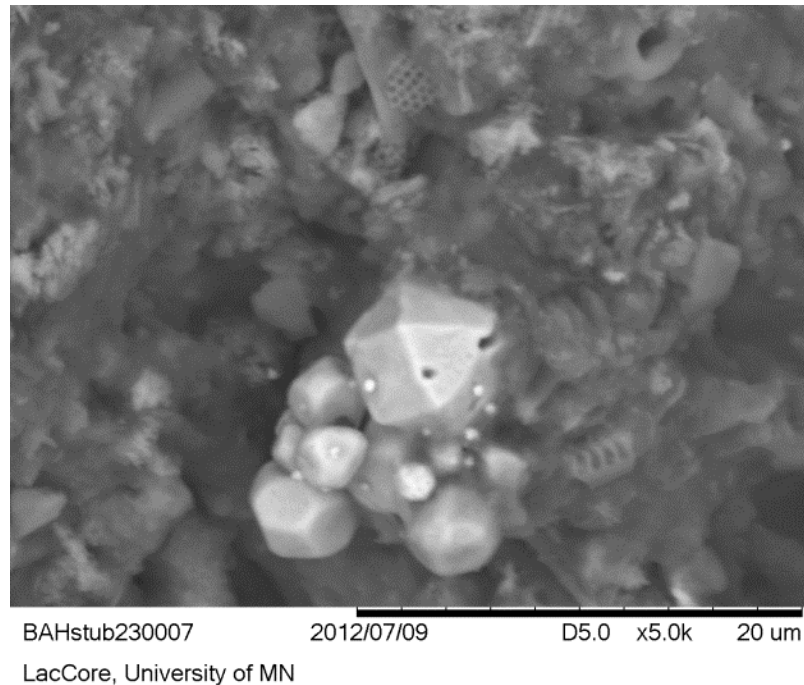


Figure 3.7: Pyrite grains found in SEM sample from Blue Hole Five Site 1 at 21 cm depth.

Unfortunately, at the time of printing this thesis, the isotopic analysis has not been completed at the University of Kentucky. Once the carbon and oxygen isotope data has been provided, the results will be published in a journal article to aid in understanding the climate change and anthropogenic impact on San Salvador Island and similar carbonate platforms.

CHAPTER 4

DISCUSSION

While Watling's Blue Hole and Blue Hole Five are relatively close to one another, the geological data obtained from the cores vary greatly. Compositionally Watling's Blue Hole has smaller grain size and less shell beds than Blue Hole Five but has more identifiable units. Both lakes have support for occurrences of oxygen-poor, sulfuric, reducing conditions. Blue Hole Five also has indications of oxygen-rich, oxidizing conditions (hematite grain seen in smear slides).

The very tops of the cores, which may represent anthropogenic impact, also differs between these lakes. Blue Hole Five contains an abundance of shells and a green flocculent layer that is mostly inorganic matter while Watling's Blue Hole contains fine to medium grained sediment with shell fragments. The LOI, Fe, and Ti data for both lakes indicate that the lakes have high inorganic pulses and a strong correlation between Fe and Ti in the very tops of the cores. Since carbonate platforms do not have inorganic materials weathering, the source for the inorganic pulses must have allochthonous sediments (originated elsewhere and transported to the blue holes). Additional studies are needed to understand the effects of anthropogenic impact on these blue holes.

The occasional inorganic pulses in the LOI data may be a record for distal dust inputs. The strong correlation between iron and titanium from Watling's Blue Hole Site 2

also supports the prospect of a record of distal dust inputs. Since iron and titanium are used as indicators for dust that is transported across the Atlantic from Africa, occasions of dust inputs may signify warm, arid climates. If this is the case, the iron and titanium data from Watling's Blue Hole Site 2 would indicate significant times of arid climates from -100 to ~300 cal. yr. BP, and ~3,400 to ~3,600 cal. yr. BP. Blue Hole Five Site 3 also suggests an arid climate from -100 to ~300 cal. yr. BP. These periods of arid climates may correlate with the arid climate of Florida and Haiti from 600 to 150 cal. yr. BP and the 3,500 to 2,500 cal. yr. BP RCC, respectively (Mayewski et al., 2004).

Current data suggest that these two lakes contain different records based on compositional analysis and geochemical data. The stable carbon and oxygen isotope data may confirm that the lakes differ in climate change records or it may lead to evidence of similar records that vary due to the result of physical differences and anthropogenic impact, at least in the very tops of the cores. The isotope data is the key to understanding the relationship between these cores in more detail.

This study was an excellent learning opportunity on patience. Samples were submitted to the University of Kentucky in February and March 2013 due to circumstances that would not allow the samples to be analyzed in house at Western Kentucky University. However, samples were not completed prior to August 2013, the date that the thesis must be completed by. This also allowed for another learning opportunity of what to do when data is not prepared in time for a conference or a paper. Many times in a professional career this may occur and therefore was a valuable experience that may need to be applied to future studies.

CHAPTER 5

CONCLUSION

To better understand the interglacial rapid climate change during the Holocene, different locations across the world must be studied as the changes do not always occur globally. Carbonate platforms, such as the Bahama Archipelago contain records of rapid climate change for the Caribbean. Studies have indicated several rapid climate change events during the Holocene and the climate characteristics in Mexico, Haiti, Florida, and other locations in the Caribbean. Past studies and reviews have shown that the climate change characteristics vary globally and even locally.

Cores from Watling's Blue Hole and Blue Hole Five on San Salvador Island, Bahamas, were studied for insight into the climate change and anthropogenic impact during the Holocene. The cores suggest different sediment records, compositionally. However, some data, such as the XRF data for iron and titanium suggest similar records at the very tops of the cores. The stable carbon and oxygen isotope study was designed and implemented to better understand the relationship of the cores from these lakes and the record of climate change for the past 6,000 years.

The story of Watling's Blue Hole and Blue Hole Five is being uncovered. However, it is just the beginning. Additional analysis, including the interpretation of the stable carbon and oxygen isotopes analysis, is needed to fully understand the relationship

between cores and impact of climate change on San Salvador Island. The analysis of cores from other blue holes or lakes on San Salvador and other carbonate islands in the Caribbean will aid in determining if there are patterns in the sediment for climate change impact on carbonate islands. The correlation of data from Watling's Blue Hole and Blue Hole Five with studies from other marine saline ponds such as those on Lee Stocking Island and Andros Island (Dix et al., 1999; Kjellmark, 1996) will help to interpret the rapid interglacial climate change throughout the Holocene in the Caribbean. Correlating these studies will assist in understanding if the climate change events were regional or just local to the site of the blue holes, ponds, and lakes on the different carbonate platforms.

Overall, Watling's Blue Hole and Blue Hole Five sediment cores have great potential to aid in understanding the climate change and anthropogenic impact on San Salvador Island. This information may also assist with understanding what lies in the future for San Salvador Island in respect to climate change. According to Steig, the RCC events during the Holocene "bear more directly on our understanding of contemporary climate change than do the events of the last glacial period" (1999). Therefore, understanding the past climate for San Salvador Island may assist with understanding the current and future trends in climate change. For as the idea of uniformitarianism geology states, "The present is the key to the past" may also be the key to the future.

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